Tropical Cyclogenesis Initiated by Lee Vortices and Mesoscale Convective Complexes in East Africa

Yuh-Lang Lin
Department of Marine, Earth, and Atmospheric Sciences
North Carolina State University
Raleigh, NC 27695-8208
Phone: (919) 515-1438 fax: (919) 515-1683 email: yl_lin@ncsu.edu

Award Number: N00014-02-1-0674
http://mesolab.meas.ncsu.edu

LONG-TERM GOALS

To understand the precursors of Atlantic tropical cyclones; the formation of a mesovortex (MV), a mesoscale convective complex (MCC), and African Easterly Waves (AEW) to the lee of the Ethiopian Highlands; the propagation of a MV and MCC, along with the evolution of the AEWs, across the African continent; and the contributing effects of these entities in the development of tropical cyclones over the eastern Atlantic Ocean.

OBJECTIVES

The scientific objectives of this effort are to answer the following fundamental questions:
(1) What are the formation mechanisms responsible for a pre-tropical cyclone (TC) mesovortex and MCC at the lee side of the Ethiopian Highlands?
(2) What are the maintenance mechanisms for the pre-TC MV and MCC as they propagate across the African continent?
(3) Is it possible that an AEW generated over the Ethiopian Highlands? What are the relationships between the AEW and the pre-TC MV and MCC?

APPROACH

(A) Numerical Modeling: To answer the first question we propose to perform a series of numerical experiments and idealized simulations by using a state-of-the-art non-hydrostatic model. The simulations will be performed using the Naval Research Laboratory's COAMPS™ model with three nested domains with grid resolutions of 45, 15, and 5 km. These simulations will be focused over, and in the vicinity of, the Ethiopian Highlands and will be performed for 60 hours starting at 0000 UTC 28 July 2000. In order to answer the second question we propose to use a much larger domain area that will cover the width of the African continent, using a grid resolution of 30 km. Several sensitivity tests will be performed to help find the necessary maintenance mechanisms responsible for the development of a pre-TC mesovortex and associated MCC, and their propagation across the African continent.

(B) Observational Data Analysis: Due to the lack of observational data from Africa, the simulation results will be verified with available analyzed data, such as NOGAPS analysis data and ECMWF reanalysis data. The analyzed model data will also be used to investigate the formation and maintenance mechanisms of the precursors and the initiation of Hurricane Alberto. Satellite data from

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Tropical Cyclogenesis Initiated by Lee Vortices and Mesoscale Convective Complexes in East Africa**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Marine, Earth, and Atmospheric Sciences,,North Carolina State University,,Raleigh,,NC,27695**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

METEOSAT will be used extensively to verify the existence or non-existence of the pre-TC MVs and MCCs.

(C) Idealized Simulations: In order to answer the third question listed in the objectives, i.e. the formation of AEW by Ethiopian Highlands and its relation with pre-TC MV and MCC, we propose to conduct some idealized simulations using the COAMPS model.

WORK COMPLETED

(1) A paper, entitled “Initiation of a mesoscale convective complex over the Ethiopian Highlands preceding the genesis of Hurricane Alberto (2000)”, has been published in the Geophysical Research Letters (Vol. 30, No. 5, 1232).

(2) A paper entitled, "Control parameters for track continuity and deflection associated with tropical cyclones over a mesoscale mountain", is under review for publication by the J. Atmos. Sci. The work detailed in this paper helps us understand the orographic effects on the formation of a secondary vortex on the lee side of a mesoscale mountain. This study is co-sponsored by a UCAR/NSF cooperative agreement (AWARE program).

(3) Mr. Christopher M. Hill, a graduate research assistant, attended the COAMPS training session and workshop at NRL in September 2002 and has learned the latest version (v.3.0) of the COAMPS model. We have made several successful idealized simulations and one control simulation relating to the initiation of mesoscale convective complexes over the Ethiopian Highlands. We are performing sensitivity experiments. We plan to present results acquired from these mesoscale simulations to the 26^{th} Conference on Hurricanes and Tropical Meteorology, to be held in May 2004. Mr. Hill is the main person supporting this task.

(4) Data Analyses. (a) We have analyzed the METEOSAT IR and VIS satellite data from EUMETSAT and constructed, from the data, the formation and propagation of pre-Alberto, pre-Isaac and pre-Joyce MCCs. This helps us determine the propagation speeds and convective cycles of the pre-TC mesovortices and MCCs. We have identified 5 stages of the MCC life cycle over the African continent. (b) We have made extensive analysis of ECMWF 0.5° initialization data. The ECMWF data was chosen for analysis due to its finer resolution, compared to the NOGAPS and NCEP reanalysis data. Thus far, results have been gathered for the cases of Alberto and Isaac. We plan to present the results in the 26^{th} Conference on Hurricanes and Tropical Meteorology. Ms. Katie E. Robertson, a graduate research assistant, is the main person supporting this task, with additional support from Mr. Hill.

(5) We have performed idealized numerical simulations using the COAMPS model to study the hypothesis that the Ethiopian Highlands may serve as significant forcing mechanism in the generation of African easterly waves, which then support the mesovortices and MCCs within maximum regions of wave PV. We are analyzing the results and comparing them with existing theories for barotropic lee cyclogenesis. We plan to present the results in the 26^{th} Conference on Hurricanes and Tropical Meteorology, and then summarize these results for submission to a peer-reviewed journal. Mr. C. M. Hill is supporting this task. In providing additional support for this task, Ms. Robertson has begun to learn the COAMPS model.

RESULTS

Based on METEOSAT-7 satellite imagery, Hill and Lin (2003) found that a tropical depression over the Atlantic Ocean on 03 August 2000, which would later become Hurricane Alberto, can be traced backward in time as a mesovortex-MCC system to the Ethiopian Highlands (EH), where this system was first seen to develop late on 28 July 2000. Using a hydrostatic mesoscale model (MASS™), Hill and Lin (2003) also found that two areas of maximum relative vorticity in the middle troposphere were generated on the lee side of the EH, with one area closely matching the development of the pre-Alberto MV/MCC system as observed from satellite data. This MV/MCC system was then observed to track westward across the African continent to the eastern Atlantic Ocean and developed into a tropical depression, as classified by the National Hurricane Center. In order to investigate the generation mechanism of the pre-Alberto MV/MCC system, we extended the preliminary numerical simulations by adopting the COAMPS model, which has more sophisticated parameterizations of physical processes and the capability in simulating the non-hydrostatic effects of the EH in generating the MV/MCC system. The model specifications used in the control run are: 45-km resolution, 42 σ-levels; 136 × 86 horizontal grid points; 60-s time interval; 60-h simulation starting on 00UTC 28 July 2000; the Kain-Fritsch (1993) cumulus parameterization; the Blackadar PBL scheme; the Rutledge and Hobbs (1993) cloud microphysical parameterization scheme. The control experiment has been performed, which shows similar results for the outer domain with 45-km resolution (Hill and Lin 2003), and we are in the process of analyzing the results in the inner domains, which use 15-km and 5-km horizontal resolutions. We are in the process of extending the control experiment into the following sensitivity experiments: (i) no latent heating, (ii) no sensible heating, (iii) no surface friction, (iv) no terrain throughout the parent domain, and (v) no terrain in Kenya (i.e. no Turkana Channel).

To understand the life cycle of the pre-Alberto MCC, we have analyzed the METEOSAT IR and VIS satellite imagery and constructed the formation and propagation of pre-Alberto, pre-Isaac and pre-Joyce MCCs, similar to analyses performed by Chang (1970). Figure 1 shows satellite imagery of the pre-Alberto MCC, which indicated that this MCC formed over the lee of EH and then propagated across the African continent to the eastern Atlantic Ocean, over which tropical cyclogenesis takes place. The average propagation speed of the pre-Alberto MCC was found to be about 11.6 ms^{-1}, although the actual propagation speed varied at different regions along its track.

We have analyzed the vorticity, mixing ratio, potential temperature, longitudinal and meridional wind, and PV fields at various heights, such as surface, 700, 500, 300, and 200 hPa, from the ECMWF 0.5° initialization data. These fields show more complicated tracks of the MV-MCC system, indicating the presence of some other physical processes, especially at lower levels, during the propagation of the MV/MCC system. These low-level physical processes will be more closely studied in the near future.

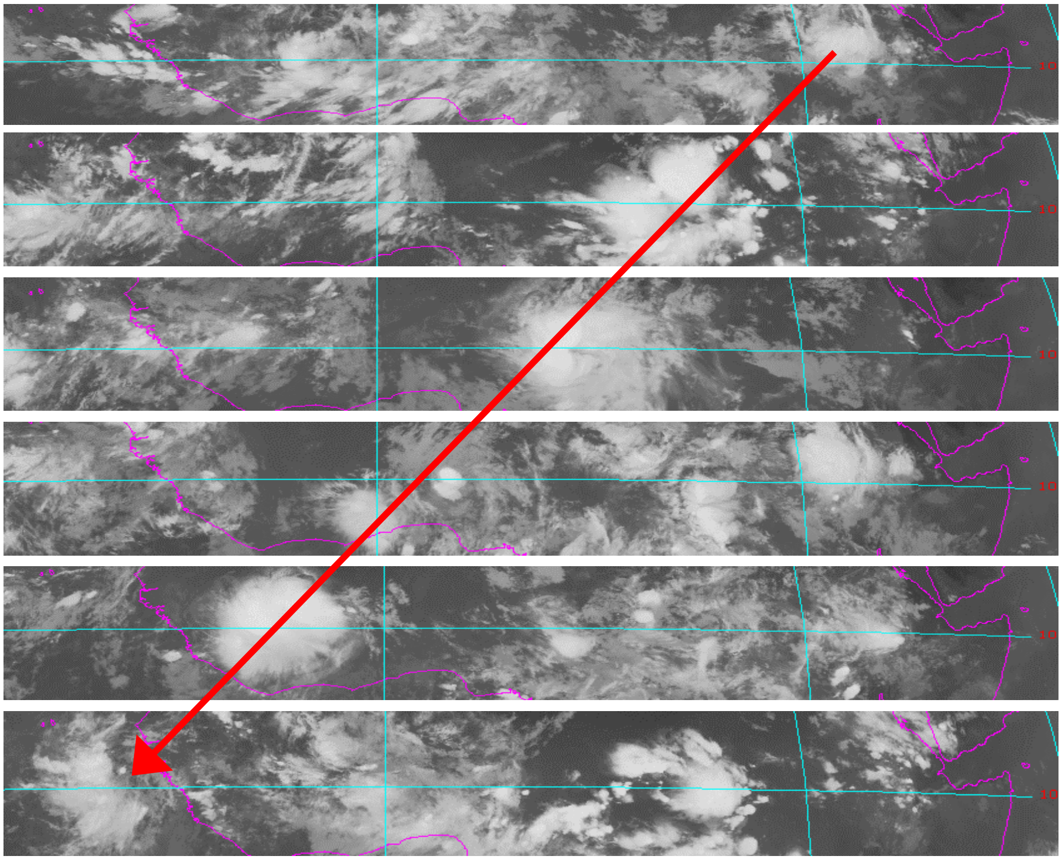

Fig. 1: Pre-Alberto mesovortex/MCC system revealed from METEOSAT-7 satellite imagery. From the imagery, it is evident that the pre-Alberto MCC originates at the Ethiopian Highlands.

Based on satellite imagery and ECMWF reanalysis data, we have estimated the areas of convective coverage of the pre-Alberto MCC and found there existed 5 stages in its life cycle while propagating across the African continent, namely Genesis I, Lysis I, Genesis II, Lysis II, and Genesis III. Analyses of pre-Isaac and pre-Joyce MCCs also reveal similar phenomena. The convective cycles of the pre-Alberto MCC were measured using the following guidelines: (i) only areas with cloud top temperatures less than or equal to –52ºC were considered for deep convection; (ii) meridional and zonal axes of the cloud were measured to the nearest whole degree in latitude and longitude; and (iii) the total convective coverage was calculated by multiplying the meridional and zonal lengths. Based on the relative humidity fields (not shown) plotted from the ECMWF reanalysis data, we hypothesize that the genesis and lysis stages of the MCC are dominated by the low-level moisture supply over the African continent. The low-level moisture is supplied from the African Rain Belt, and transported by a seasonal eastward extension of the West African Monsoon. The African Easterly Jet, to the south of the Sahara Desert, may contribute to the Genesis III stage of the MCC.

Frank (1970) briefly mentions the possibility that easterly waves may develop downstream of the Ethiopian Highlands (EH) as a result of orographic influence on the easterly flow. However, based on a statistical study of upper air observations from Khartoum, Sudan, Burpee (1972) argued that the African easterly waves do not develop immediately downstream of the EH. On the other hand, based on the Hovmoller plot of meridional wind, vorticity and other fields for pre-Alberto mesovortex/MCC system from the analysis of ECMWF 0.5° data, we found there was a wave structure associated with the mesovortex and two to three other vortices were embedded within the wave across the African

continent. The origin of the waves seems to be consistent with that of the mesovortex, i.e. on the lee of the EH. Thus, we hypothesize the AEW is generated by influence of the EH and mesovortices tend to form within regions of maximum vorticity of the AEW. In order to prove this, we have performed an experiment using the COAMPS model with uniform basic winds traversing idealized EH topography on a β-plane centered at 10°N. The uniform basic wind speed is assumed to be –10 ms^{-1}, which is comparable to the observed propagation speed of AEWs. Figure 2 shows the plot of streamlines and potential vorticity after 180 h simulation for the case with U = -10 ms^{-1}. As can be seen from the figure, three vortices were generated by the EH and embedded in the wave, which can be interpreted as an AEW. The wavelength is about 2000 km, which is consistent with observed wavelength of AEW. Thus, the results are promising. We are analyzing the numerical results, surveying existing theories for large-scale flow over mountains, and planning to perform more numerical experiments to understand the underlying dynamics.

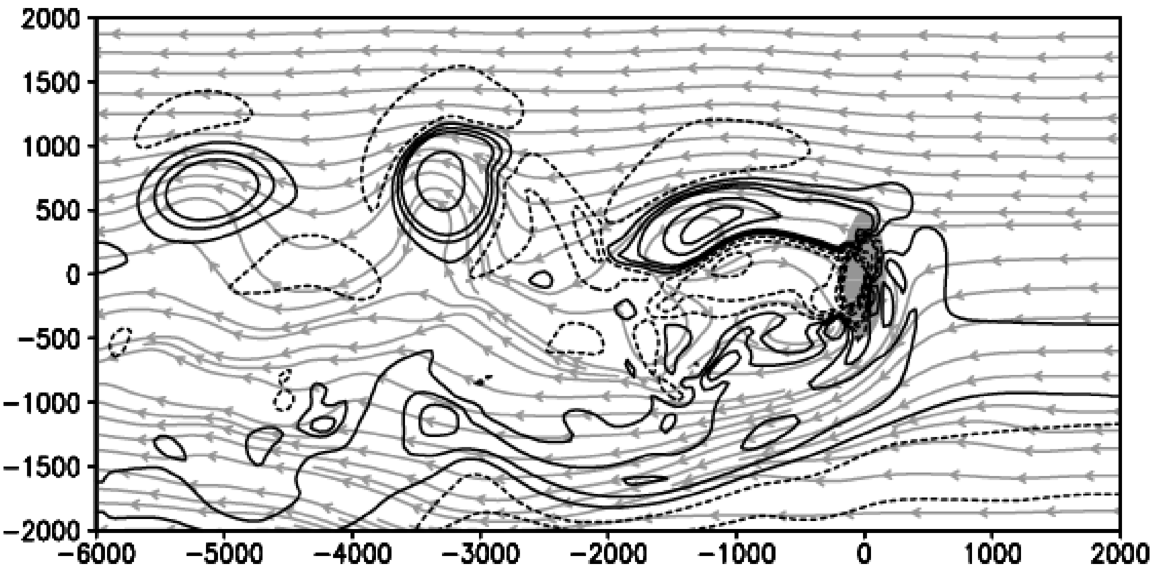

Fig.2: COAMPS™ simulated potential vorticity and streamlines at σ =250 m and t = 180 h for uniform flow of U = -10 ms^{-1} past an idealized EH topography. The contour interval is 0.04 PV units for –0.1 < PV < 0.1, and 0.2 PV units for PV < -0.1 and PV > 0.1. Solid (dashed) contours are positive (negative) PV values. The shaded oval represents idealized terrain > 500 m.

IMPACT/APPLICATIONS

The understanding and capability of predicting the formation and maintenance of the MV/MCC systems and associated African easterly waves (AEWs) over the African continent are essential in understanding and predicting the eventual formation of tropical cyclones over the eastern Atlantic Ocean.

RELATED PROJECTS

UCAR/NSF AWARE project (P.I.: Dr. Y.-H. "Bill" Kuo) on effects of orography on TC track deflection and rainfall distribution associated with the passage of tropical cyclones over a mesoscale mountain.

REFERENCES

Chang, C. P., 1970: Westward propagating cloud patterns in the tropical Pacific as seen from time-composite satellite photographs. *J. Atmos. Sci.*, **27**, 133-138.

Frank, N. L., 1970: Atlantic tropical systems of 1969. *Mon. Wea. Rev*., **98**, 307-314.

Hodges, K. I., and C. D. Thorncroft, 1997: Distribution and Statistics of African mesoscale convective weather systems based on the ISCCP Meteosat imagery. *Mon. Wea. Rev*., **125**, 2821-2837.

PUBLICATIONS

Hill, C. M., and Y.-L. Lin, 2003: Initiation of a mesoscale convective complex over the Ethiopian Highlands preceding the genesis of Hurricane Alberto (2000), *Geophys. Res. Lett.*, **30**, No. 5, 1232.

Lin, Y.-L., S.-Y. Chen, and C. M. Hill, 2003: Control parameters for track continuity and deflection associated with tropical cyclones over a mesoscale mountain. *J. Atmos. Sci.*, in review.

Lin, Y.-L., K. E. Robertson, and C. M. Hill, 2003: Origin of African Easterly Waves. Part I: Observational Evidence. In preparation.

Lin, Y.-L., C. M. Hill, and K. E. Robertson, 2003: Origin of African Easterly Waves. Part II: Numerical Experiments. In preparation.